Use of radar technology to determine freeboard in steel ladles

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INTRODUCTION

The distance between the upper ladle rim and the slag/steel surface, also called *freeboard*, is an important factor that needs to be balanced out to achieve melt shop productivity and safety goals. The paper presents a method to measure the freeboard as the ladle goes out of the tapping pit and analyzes the results of trials performed in an integrated mill located in the United States.

MOTIVATION

When a BOF or EAF pours the produced steel into an empty ladle, process known as *tapping*, the operation has to be monitored closely by an operator to fill up the ladle up to an optimum level by controlling the *freeboard*, v.g. the distance between the ladle rim and the surface of the steel/slag.

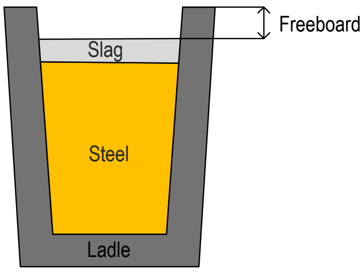


Figure: Freeboard definition

The *optimum freeboard* is a compromise between two important goals: maximizing heat weight while providing enough room to prevent spills caused by boiling steel and slag foaming during secondary processes like VTD, RH Degassing or even argon stirring during LMF practices.

The task of determining when to stop tapping is usually executed by an operator; this is a difficult task because dust and smoke usually block the view, glaring from the steel being poured forces the use of special shades and for safety reasons the operator has to be far removed from the tapping pit, or even supervise the whole process through video cameras.

While planning the trial that led to this paper we identified two interesting situations to perform the measurement freeboard: during tapping while the ladle is being filled up and right after tapping when the ladle is moving out of the tapping position.

Measuring freeboard during tapping might be used to control an *automatic tapping procedure* where the operator is removed from the control of the vessel. This would be the main goal of the technology being trialed but placing the equipment in the right spot of the tapping area of the plant we visited proved to be difficult as explained below.

On the other hand, determining the freeboard right after tapping is easier and still has many benefits: provides safety alerts to the secondary process operators when a ladle is overfilled, help refractory managers to figure out the slag line on each ladle and enable a consistent method to correct tapping procedures, either manual or automatic.

EXISTING FREEBOARD MEASUREMENT TECHNOLOGIES

Freeboard measurement has been a long standing goal on steel mills and several technologies have been tried most of them focused on providing feedback to automatic tapping procedures. Video feeds with artificial vision algorithms were attempted [1], algorithms based on the tapping weight and an estimation of the geometry of the ladle were also developed and used for this purpose [2] and there are physical probes in the market that can be submerged into the ladle [3]. Another possibility would be using lasers or ultrasonic distance meters.

The radar technology we trialed is based on a very straightforward measuring principle and have a robust and repetitive performance due to their tolerance to smoke and dust environments.

ADVANTAGES OF RADAR TECHNOLOGY IN STEEL PLANTS

Radar vs. Optical based technologies
The cutting edge radar scanner solution we tested is superior to laser and other optical based technologies for several reasons. The main reason is that optical wavelengths cannot go through smoke and dust in suspension, also optical equipment requires serious maintenance efforts to keep the lenses clean in typical melt shop environments; furthermore lasers consist of many tiny moving parts that – after some time – fail to withstand tough environmental conditions like dirt, shocks and vibration.

Owing to the different wavelengths of laser light (approx. 1µm) and radar (4mm), the impact of environmental conditions on the quality of the radar measurements is minimal. While the radar “ignores” smallest air particles, laser light reflects on dust and fog, leading to scattering of the laser light. Laser cannot detect objects “lying behind” the smoke or dust curtain.

The following figure visualizes the differences:

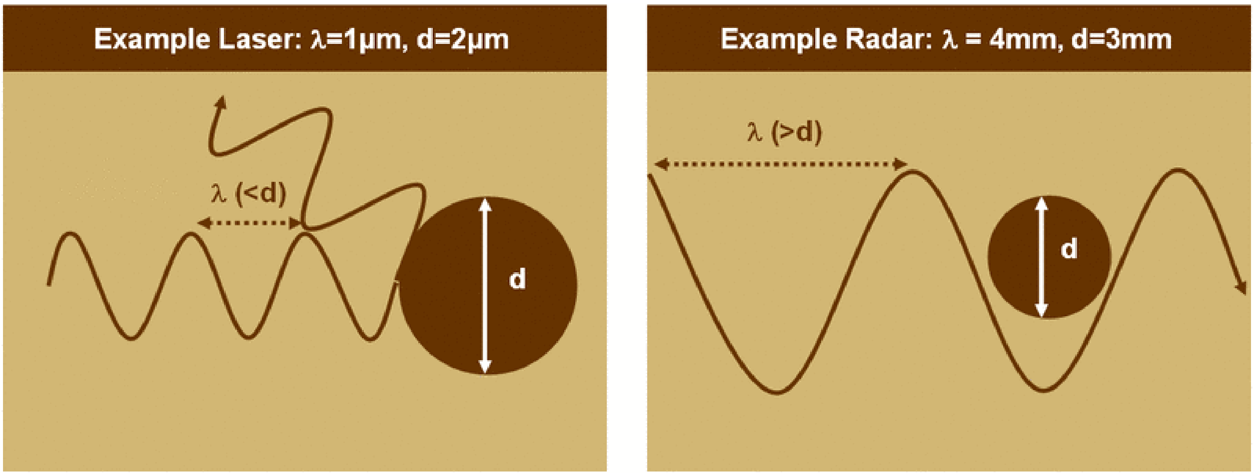


Image: Differences between laser and radar technologies

TRIAL OF RADAR EQUIPMENT FOR FREEBOARD MEASUREMENT

The trial was conducted in a BOF facility of a large integrated steel mill located in North America during August of 2015. The primary goal of the test measurements was to prove the full functionality of measurements conducted with the iLDR™ sensor near or in the immediate environments of the BOF and the steel ladle.
The secondary goal was to produce first measurement data to approach a basis for the development of a full fledged automation solution for the following two process goals:

BOF Autotap (Dynamic):
Filling height measurement inside the ladle during tapping

BOF Freeboard (Static):
Determination of static distance between filling height (slag/steel level) and rim of ladle after tapping

iLDR™ (LinearDynamicRadar)
All test measurements were conducted with the iLDR™ (indurad LinearDynamicRadar) DN 100 with a high-focus radar beam.

The iLDR™ radar sensor offers reliable measurement of 1D distances between the radar frontend and any surface capable of reflecting microwaves. The maximum measurement distance is about 400 m (1000'). The iLDR™ offers an extremely high update rate of up to 1000 measurements per second and an accuracy of <1mm (1/32''). The in-built RadarProcessingUnit (iRPU) offers a basic easy web based management and service interface, visualizing current and historic measured data.

Image: the iLDR™ Distance Sensor

MEASUREMENT OF FREEBOARD DURING TAPPING

The original plans foresaw to take measurements through the operator control windows into the BOF. As the three layers of the security glass did not permit the iLDR™ radar beam to go through, an alternative test measurement setup had to be found.

The figure below shows the three first test positions (red arrows + blue arrow) of the iLDR™ with windows onto the ladle. iLDR™ directly focusing on ladle.

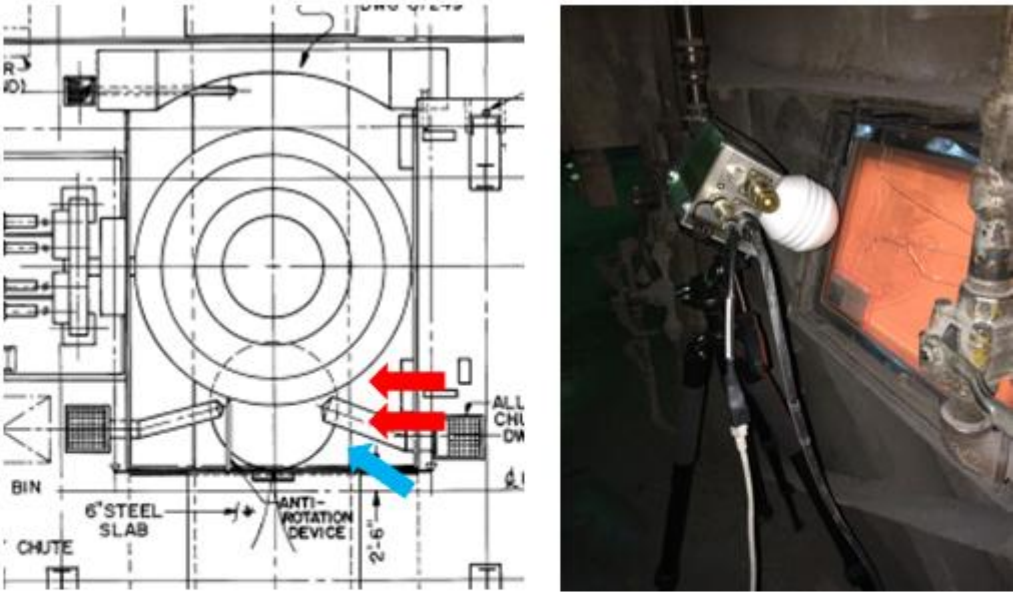


Image Left: Tentative locations of sensor for tapping measurement
Image Right: Sensor installed in position 3

The photography shows the test measurement position 3, represented by blue arrow. In this position, the windows could be taken out for tests. During tapping, however, on that particular window the sight onto the ladle was blocked by the tilted BOF furnace.

STATIC FREEBOARD MEASUREMENT

Sensor Arrangement
For this test we selected a position on the balcony that overlooks the ladle movement area underneath
The orientation of the sensor can be seen indicated by the green arrow in the left image.

Image Left : Green arrow indicating location and X-Y orientation of sensor
Image Right: location of tripod and Y-Z angle.

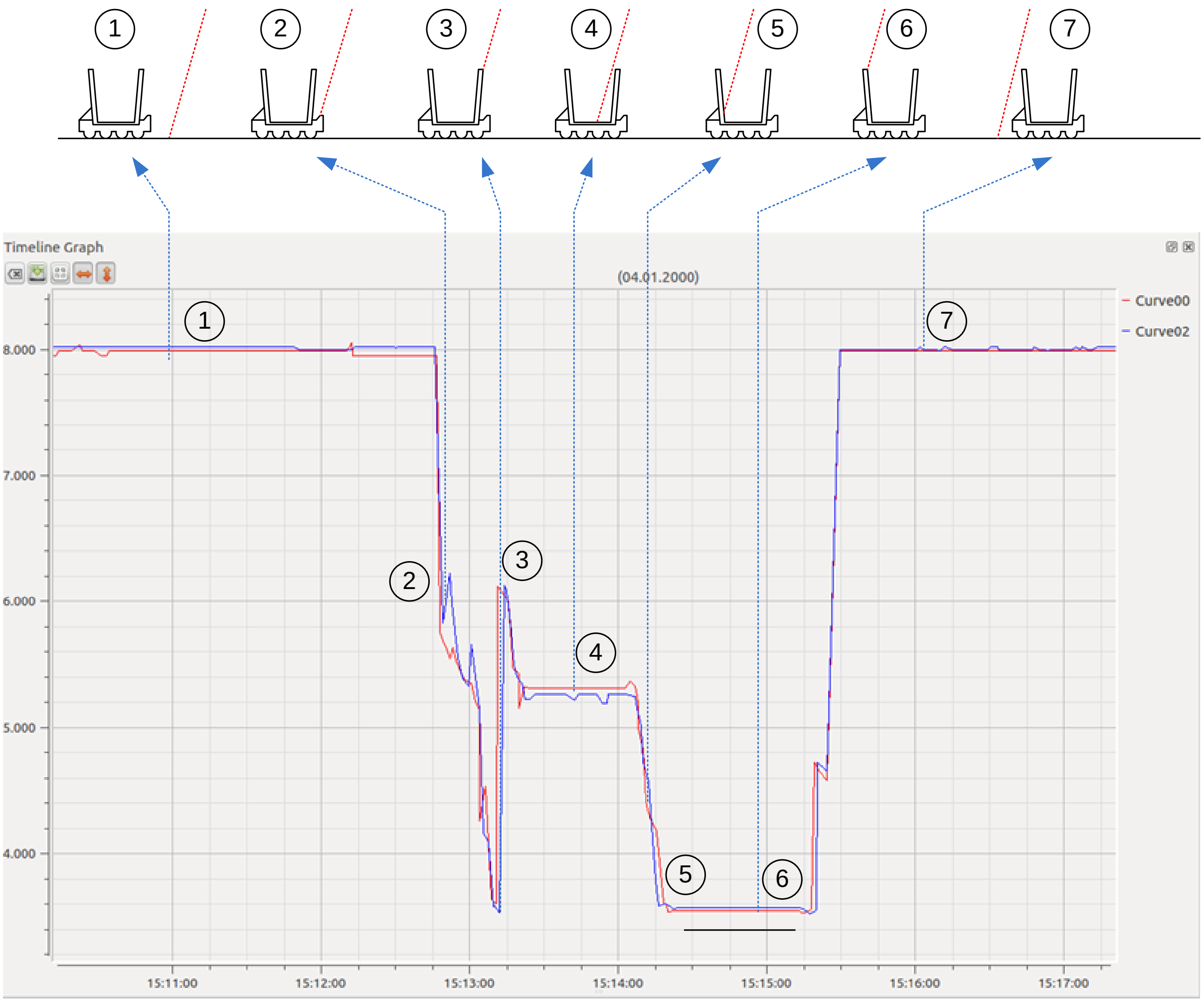
The orientation of the sensor was not perfect but allowed us to evaluate the radar beam performance under typical conditions. On a permanent setup the sensor can be positioned closer to the middle of the ladle car tracks and looking vertically down to minimize the distortion introduced by the angles.

The plan for the test was capturing the incoming empty ladle and to perform measurements during this process. After tapping, the full ladle could be measured a second time, this time with surface measurement in high heat, smokes and fumes.


Images: Close up images of sensor arrangement

For both recordings we started recording the raw radar measurements as soon as the ladle car appeared into view and at the same time we used a video camera to record visual footage. We then uploaded all the data to our servers to perform a basic calculation of distances.

Results for incoming (empty) ladle



1 – The sensor is pointing to the floor.
2 - iLDR™ picks up reflections from outer structure of ladle car
3 – The radam beam detects the ladle rim. The sudden peak after 3 is due the multipath reflections that appear in uncalibrated measurements. These reflections can be filtered out after the instrument is properly calibrated in the final setup.
4 – Detection of the bottom of the ladle
5 – The operator stopped the car for one minute at this point so the graphic looks distorted.
6 – Detection of the ladle upper rim
7 – Floor level

Results for outgoing (full) ladle

1 – Floor level
2 – Sensor detects the upper rim and ladle wall. Multipath propagation generates reflections due to the uneven surface.
3 – Steel / Slag level
4 – Upper rim and ladle wall with multipath propagations
5 – Floor level

Analysis of the results

The resulting graphics and measurements were according to our expectations, even surfaces like the floor, ladle bottom and steel/slag were measured with consistency. Uneven surfaces produced multipath propagation reflections that can be filtered out during the necessary calibration period in a final installation. Heat, smoke and dust did not affect the equipment nor the results.

CONCLUSIONS

An iLDR radar measuring device was installed in the BOF tapping area of a large American steel producer. Data was recorded while the ladle was entering and leaving the tapping pit. The resulting measured distances and patterns were according to initial expectations yielding repetitive values and remaining unaffected by the environment.

Calibration and custom filters will be necessary to eliminate multipath propagation reflections that might affect the measurement of the upper ladle rim. The final customer has expressed the interest of installing the radar permanently in their BOF to evaluate the performance on a longer period of time.

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